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Motor coordination variability induced by conscious control of movement

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The present study examined an underlying assumption of the conscious control theory of stress-performance relationship: An attempt to control movements consciously in a later stage of learning causes the movements to regress to an initial stage of learning. Ten male subjects performed an underhand ball-throwing aiming at a target by non-dominant hand. After 150 practice throws, the subjects performed 30 throws across which reproducing same limb trajectories was required. Inter-trial variability of two kinematic measures, namely joint coordination and hand positions at the end of takeback and ball release, was analyzed as an index of automaticity. The results showed that trying to control movements consciously degraded performance and made the coordination between the hip and arm joints unstable. However, this instability was qualitatively different from the instability at the beginning of practice. The findings imply conscious control does not lead movements to the initial state: Rather, it impairs an intrinsic coordination of the whole body.

Key words: Motor coordination, Conscious control, automatization

Introduction

On an issue that social-evaluative stress impairs motor performance, a perspective focusing on a control mode of movement is presented by the conscious control theory (Baumeister, 1984; Masters, 1992; Willingham, 1998). The theory proposes that performers under social-evaluative stress should be motivated to perform well and change the control mode from autonomous mode with procedural memory to conscious mode with declarative memory. Performance is impaired because this activity disrupts automaticity of the control which is acquired through practice. The disruption of learned automaticity is called "*deautomatization*" (Deikman, 1969).

This theory holds two underlying assumptions for conscious control of movement, one of which remains to be empirically tested. One is that conscious movement control gives harmful effects on automaticity of the control. The other is that skilled movements regress to an initial state of learning as a result of *deautomatization*. The former assumption is supported by some studies, in which conscious monitoring of specific movements caused skilled performers to degrade performance (e.g., Langer & Imber, 1979; see Masters, 1992). These findings imply that paying attention to the movement impaired automatic control which governs skilled behaviors. However, none of these studies show the data comparing movements controlled consciously with movements at the beginning of practice trials. Therefore it is not clear whether

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the movements regress to an initial state.

The purpose of the study is to examine whether the conscious control causes movements to regress to an initial stage of learning. In other words, the degree of automaticity of control under conscious control is compared with that in early-practice, late-practice trials. Using an underhand ball-throwing task aiming at a target, the degree of automaticity of control is represented by inter-trial variability in two kinematic measures: One is joint coordination and the other is hand positions at the end of backward arm swing (*takeback*) and at the release.

Joint coordination in throwing has naturally high degrees of freedom, so that the coordination style is highly unstable in an early stage of learning. Performers have a tendency to use a single coordination style for the given task (Newell & McDonald, 1994), so that the coordination style becomes stable through practice, supposedly by automatization. If executing the movement with declarative knowledge in the late stage leads to *deautomatization*, then the coordination will take the same style as the initial style and the variability will increase again.

The hand positions at the takeback and release are another important factors influencing accuracy of ball direction and are determined as a result of joint coordination (e.g., Hore, Watts & Tweed, 1996; Rossum & Bootsma, 1989). Thus it will also show lower inter-trial variability after practice and higher variability under conscious control.

Method

Subjects

Subjects were 10 male volunteers, ranging in age from 19 to 27 years. All subjects were naturally dominant right-handers.

Task & apparatus

The experimental task chosen was an underhand ball-throwing maneuver with tennis balls using the non-dominant hand, aiming at a target accurately. The target was composed of four concentric circles. Diameter of the inner circle, for which the subject aimed, was 8 cm and the diameters of the other circles increased by 16-cm intervals. The target was placed so that the bullseye was at a height of 1 m and at a distance of 3.3 m from the subject.

The displacement of the arm joints was recorded with a Hi-8 video camera (SONY, Japan, Tokyo), which was placed at a distance of 3 m from the left side of the subject and at a height of 1 m. The performance score on the target was filmed with a 8 mm video camera (SANYO, Japan, Tokyo) behind the subject.

Procedure

The LEDs were attached to the shoulder, elbow, wrist, hand, hip and knee at specific anatomical positions. These LEDs were used to calculate the angles at the shoulder, elbow, wrist and hip.

The subjects performed the throwing task in two sessions: A practice session and a performance session. The practice session was the learning session which consisted of 5 blocks of 30 trials, with 3-5 min rest between the blocks. The subjects were instructed to attempt to aim at the bullseye of the target as accurately as possible. The performance session consisted of 1 block of 30 trials, in which the subjects executed the throwing movement consciously.

In the performance session the subjects were instructed to aim at the target while reproducing the same limb trajectories throughout the session. In order to stress the conscious reproduction of the trajectories, feedback about consistency of the trajectories was presented after the completion of every five trials. The trajectories of the every five trials, that is trials for 5, 10, 15, 20, 25 and 30, were superimposed upon that of the first trial in the performance session (defined as the reference trial) by Quick-MAG system 1 (Quick-MAG system 1, OKK inc., Japan, Tokyo). The information about the differences between these trajectories was given to the subject verbally in terms of spatial consistency in (1) a hand position, indicated by the hand LED, at the end of takeback, and (2) a hand trajectory during forward arm swing[1].

Data analysis

All the data were collected only for the first and the last 10 trials of the practice session, together with the first 10 trials of the performance session. These trials were called the pre-practice phase, the post-practice phase and the test phase, respectively. The kinematic data were sampled for 3 s. The displacement of the LEDs was digitized at a sampling frequency of 60 Hz and filtered by using a Butterworth lowpass filtering. Cutoff frequency was 2.4-4.8 Hz, which was determined by Hinrichs (1982)'s technique.

The performance scores were measured in terms of Absolute Error (AE) and Variable Error (VE). The AE indicated a mean absolute distance from the bullseye to the actual point of the ball impact. The VE meant a standard deviation of the absolute distances (see Schmidt, 1988, chapter 3).

The joint coordination was indicated by cross correlations with zero time delay between the angles at the shoulder, elbow wrist and hip (see McDonald Emmerik, & Newell, 1989; Vereijken, Emmerik, Whiting, & Newell, 1992). Angular displacements were used for calculating the cross correlations. Cross correlation analysis was performed on time course of the forward arm swing, which started at the end of takeback and terminated at the ball release. Each joint angle was defined as the angle between two segments. The shoulder angle, for example, was an angle between the trunk (from the shoulder LED to the hip LED) and the upper arm (from the shoulder LED to the elbow LED). The variability of the joint coordination in each phase was represented by the standard deviation in the cross correlations in the phase.

1. Although the hand position at the release was the most useful variable for the throwing performance (see Discussion), the information of the release consistency could not be presented to the subjects for methodological limitation.

Results

Performance scores

Table 1 shows mean performance scores. A one-way ANOVA with repeated measures, which was conducted on the AE and the VE separately, revealed a significant main effect of the session in the AE, $F(2,18) = 12.59$, $p < .01$ and in the VE, $F(2,18) = 5.47$, $p < .05$. A post hoc analysis showed that both the AE and the VE were reduced significantly in the post-practice phase and the AE increased significantly in the test phase.

Table 1. *Mean Absolute Errors(AEs)and Variable Errors (VEs)on the performance scores*

	Phase		
Error	Pre-preactice	Post-practice	Test
AE	24.9 (5.51)	17.1 (5.40)	28.3 (9.66)
VE	12.5 (2.58)	9.2 (2.69)	11.36 (2.02)

Standard deviations in parentheses

Joint coordination variability

Figure 1 shows the mean within-subject variability of cross correlations. A two-way repeated measures ANOVA (6 linkages × 3 phases) revealed that there was a significant interaction, $F(10,90) = 5.47$, $p < .05$. The shoulder-wrist coordination became more stable in the post-practice phase than in the pre-practice phase. The shoulder-hip and elbow-hip coordination was more variable in the test phase than in the post-practice phase. The elbow-wrist coordination in the test phase was more stable than in the pre-practice phase.

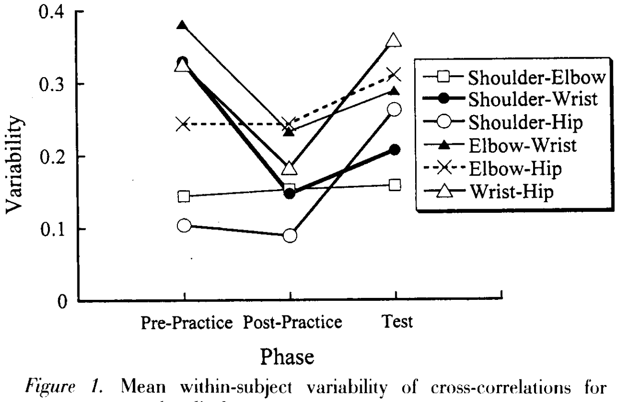

Figure 1. Mean within-subject variability of cross-correlations for angular displacement.

Hand position variability

Figure 2 shows examples of the hand trajectories in the pre-, post-practice and the test phases. The variability in hand position at the end of takeback and at the release was analyzed separately. At the end of takeback, mean variability scores (cm) in the pre-, post- and test phase was 7.98, 4.93 and 7.26 for the horizontal, 3.76, 2.93 and 6.45 for the vertical direction. A one-way ANOVA with repeated measures was conducted for the scores in each direction separately, showing a tendency of a main effect in the vertical direction (F (2,18) = 2.71, $p < .10$). A post hoc analysis showed that the score in the test phase was higher than in the post-practice phase. At the release, the score was 4.46, 3.93 and 4.98 cm for the horizontal, 6.50, 5.00 and 6.53 cm for the vertical direction. An ANOVA showed no significant main effect.

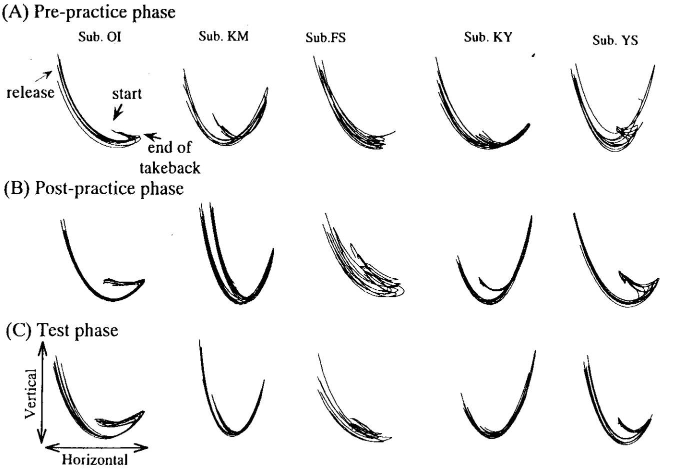

Figure 2. Examples of the hand trajectories in the pre-practice(A), post-practice (B) and test (C)phases.

Discussion

The conscious control theory predicts that when conscious control impairs automaticity of control, movements regress to an initial state of learning. However, the present study shows two findings against this prediction in the analysis of the joint coordination variability. First, in the test phase the shoulder-elbow coordination, which became stable with practice, did not regress to the initial, variable state. Second, the shoulder-hip and elbow-hip coordinations, which kept consistent degree of variability across the practice trials, showed higher degree of variability in the test phase.

These findings reveal that excessive control of the arm movement makes the coordination style unstable. However, the coordination style is different from the initial coordination style, so that regression to the initial state of learning does not happen. Considering that the variability in the coordinations between the hip and the joints in arm increased, excessive control of the arm movement disrupts the coordination of the whole body.

However, this conclusion would be premature for some reasons. First, the joint coordination became significantly stable with practice only in one of six joint linkage. Therefore the variability of the joint coordinations was not necessarily a useful indication of the degree of automaticity. Figure 2 shows Subject FS and YS produced inconsistent trajectories in the post-practice phase in spite of the consistent performance scores. It implies that a single preferred mode of the coordination (Newell et al., 1994) is not necessarily chosen for the underhand throwing task, or the 150 practice-throws were insufficient for the kinematic stabilization.

Secondly there is a possibility that the subjects' learning strategies in the early stage were not to reproduce the limb trajectories consciously. In the present study the subjects were required to pay attention to all the limb movement during throwing. However, because throwing movement has a number of degrees of freedom, consistent movements across trials are not necessarily essential for excellent performance. The release variables (the position, angle and velocity) have an important role for throwing performance (e.g., Hore, et al., 1996; McDonald, et al., 1989). Therefore the subjects might focus their attention only to the release condition in the early stage of learning.

It is important to note that in the test phase the variability of the hand position at the end of takeback increased marginally, about which the subjects were given the information feedback. Some studies suggest that feedback produces overmodification from trial to trial and prevents the learner from generating stable behavior (*the guidance hypothesis*, Salmoni, Schmidt, & Walter, 1984; see Schmidt, Young, Swinnen, & Shapiro, 1989; Wulf, & Schmidt, 1994 for evidence). According to this view, the subjects in this study were too much influenced by the knowledge of performance, although the feedback was given for only two trials out of ten trials in the test phase. If so, the knowledge of performance which the performers can get would be a key to orient the changes in movement and to lead the deautomatization.

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